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INVESTIGATION OF AIR MASSES LABELLED BY ARTIFICIAL AND NATURAL NUCLIDES TO SOLVE SOME EARTH ATMOSPHERE DYNAMIC PROBLEMS

(Based on sea expedition materials)

INTRODUCTION

Investigation of geographical distribution of radioactive substances in the near-ground air and at various altitudes gives an important information about some large-scale processes in the atmosphere.

During the period from 1958 up to 1964 systematic study of the radioactive substances concentrations in the ocean atmosphere has been made. Expedition ships of the USSR Academy of Sciences and the Hydro-Meteorological Service Office were used for this purpose. For this time in twelve sea-expeditions the aquatoria of Pacific, Atlantic and Indian Oceans were inspected from 72° N up to 70° S.

Necessity of this work was specified not only by lack of the data on radioactive substances concentrations in the atmosphere above the Global Ocean, but also by the fact, that investigation of large-scale meteorological processes above wide sea surface is easier, than above dry land due to large air masses thermal stability.

Major part of the investigations was devoted to study global distribution of some nuclear explosions products and Beryllium-7.

Nuclear explosion products stratospheric reservoir, as known, was formed as result of ascending of main part of powerful explosions artificial radioactivity to high altitudes (1).

Altitude distribution of Beryllium-7, produced in interaction of cosmic protons and neutrons with nitrogen

and oxygen nuclei is about the same as for nuclear exposions products (2). Location of Beryllium-7 maximum concentrations is approximately at the same altitudes (15-25 kilometers), at which artificial radioactivity maximum concentrations are observed.

Unlike nuclear explosions products ascended to the stratosphere only by powerful explosions, Beryllium-7 is forming continuously in the atmosphere with nearby steady rate, determined by proton flux penetrating into the earth atmosphere.

Beryllium-7 concentrations observed in the near-ground air are determined not only by rate of its forming and radioactive decay, but also by steady large-scale meteorological processes.

1. Experimental Methods of Investigation

During the expeditions on the ships daily sampling of radioactive air was made by filtration of large air volumes ($\sim 10^5 m^3$) through fine-fibrous fabric filter of type ФПА -15А, which provides practically full trap of aerosol particles of size up to some hundredths of micron.

Integrated beta-gamma-activity and some radioactive substances concentration were measured in collected samples.

Beta-activity was measured with scintillation, end-window and gas-flow counters of near to 4π -geometry. Gamma-activity was measured with scintillation spectrometers.

Thallium activated sodium iodide well-type crystals were used (dia.50 mm, thickness 60 mm, well-dia. 16 mm).For 661 kev-gamma ray the resolution averages 10%. Scintillation counter pulses were fed into multichannel differential pulse height analyzer. With the scintillation gamma-ray spectrometer were analysed samples having activity more than $5 \cdot 10^{-11}$c. Beryllium-7 and Cesium-137 concentrations in the samples containing above two-year old fission products were

determined by corresponding lines intensity on a spectrogram. Concentrations of Cerium-144, 141, Zirconium-95 and Niobium-95, Ruthenium 103, 106 in samples containing less than one-year old fision products were determined by corresponding lines intensity on a spectrogram. In cases, when Tungsten-181 and Beryllium-7 concentrations were low in comparison with those of other radionuclides, they (3),(4) were previously extracted by radiochemical method with following measurement in gamma-spectrometer.

Stroncium-89, 90 and Tungsten-185 concentrations were determined by known radiochemical methods (3), (5) and yielded radioactivity was measured with corresponding beta-counter.

For measurement of radioactive products concentration in the upper atmosphere (up to 30 km) radiosondes of two types were used. They were launched from the expeditionary ships which also carried out the observations.

Radioactive products summary intensity was measured with radiosonde type PK-1 (6) intended for study cosmic radiation intensity variations. Radiosonde PK-1 threshold of sensitivity to nuclear expositions products radiation is different for the stratosphere of tropical (low) and mean latitudes and is $5 \cdot 10^{-9}$ and $5 \cdot 10^{-8}$ c/st . m^3 respectively.

The assemblies of thallium activated sodium iodide crystals (40x40 mm) with photomultiplier ФЭУ -13 were used as gamma-detectors. The pulses were analysed by kick-sorter АИ -100 with digital printer Б3-2.

Figure 1 shows typical gamma-spectrograms in the energy region 0.15 ÷ 1.5 Mev obtained by the radiosonde, launched and landed on April 8, 1963 in the point of 16º N,180º. In the most spectrograms it is clearly seen three peaks corresponding to 0.33; 0.5 and 0.75 Mev. The first peak is due to gamma-rays from Chromium-51, used for instruments operation test. The peak corresponding to 0.5 Mev-energy is caus-

ed mainly by annihilation radiation, and the 0.75 Mev-peak - by gamma-rays from Zinconium-95 and Niobium-95. Sprctrometric radiosonde threshold of sensitivity to the mentioned above products in the stratosphere is $(1-4) \cdot 10^{-10}$ c/st. m^3. Data on distribution of unscattered gamma-ray flows obtained with such a radiosonde at various altitudes permit to calculate vertical distribution and absolute value of concentration of Zinconium-95 and Niobium-95.

2. Geographical Distribution of Activity in the Near-Ground Air

Study of geographical distribution of activity in the near-ground air shows as a rule slight change of active products concentration along certain latitude zones and sharp change of concentration along meridian.

This is in a good agreement with known meteorological fact, that mean zone wind velocities in the troposphere are about one order of magnitude higher than mean meridional components of wind velocity.

Several collected experimental data are shown in Fig.2.

Beryllium-7 distribution along meridian according to the data obtained during the expedition on the ship "M.Lomonosov" (March 1961 - June 1961) from 50° N up to 30° S in the Atlantic Ocean is plotted in a-1. The plot a-2 shows Beryllium-7 distribution according to the data obtained during the expedition on the ship "Kooperatsija" (January 1962 - February 1962) from 0° up to 67° S in the Atlantic and Indian Oceans.

The plot a-3 shows Beryllium-7 distribution from the data obtained during the expedition on the ship "Ob" (November 1962 - May 1963) from 72° N up to 70° S in the Atlantic and Indian Oceans. The latter data obtained between 34° S and 70° S are average values from measurements in six meridional sections.

Comparison of these three distributions shows, that mean

Beryllium-7 concentrations in the same latitudes are similar, and meridional distribution is identical.

Concentration maxima locate in thirtieth latitudes N and S and in pole areas, while concentration minima locate in equator zone and in zone of fiftieth and sixtieth degrees N and S.

Some asymmetry of Beryllium-7 distribution in the Northern and Southern hemispheres attracts attention. Concentration maximum and minimum values in the Southern hemisphere are noticeable lower than those in symmetrical areas in Northern hemisphere.

Probable causes of observed distribution asymetry might be season variations of the near-ground Berillium-7 concentration as well as rate difference of circulation processes in the armosphere of the Southern hemisphere as compared with those in the Northern hemisphere.

The plots b-1 and b-2 show distribution of Tungsten-181 according to the data obtained during two expeditions on the ship "Ob" (December 1958 - April 1959) from 57º N up to 67º S in the Atlantic and Indian Oceans and on the ship "Vitjaz" "November 1959 - April 1960) from 43º N up to 32º S in the Pacific and Indian Oceans. Tungsten-181 appeared in the stratosphere as a result of series of nuclear weapon tests in a tropical area of the Pacific in summer 1958.

The cited here activity levels relate to the date of Tungsten formation. In spite of essential decrease of Tungsten-181 concentration during one year the character of meridional distribution during this period did not change. Maximum concentration of Tungsten-181 was observed in 30º N and in 15º S. Minimum concentration was observed in equatorial zones and in 50th latitudes of both hemispheres.

The plot b-3 illustrates Tungsten-181 distribution according to the data obtained during expedition on the ship "Ob"

(November 1962 - May 1963) from 72° N up to 70° S in the Atlantic and Indian Oceans. Radioactive Tungsten entered the stratosphere in results of nuclear weapon tests in 1962. The plot- b-3 shows, that maximum concentrations were observed in 30th latitudes of both hemispheres and at sea coast of the Antarctic, and minimum ones - in equatorial zone and in 50th - 60th latitudes of both hemispheres.

Plots c-1, c-2, c-3 represent meridional distribution of Cerium-144 concentration, its summary beta-activity according to the data obtained during expeditions on ships "Ob" (December 1958 - April 1959), "Vitjaz" (Nov.1959 - April 1960) and "M. Lomonosov" (March 1961 - June 1961).

Peculiarity of radionuclides distribution considered above consists in the fact, that maximum concentrations of radionuclides are in 30th latitudes of Northern hemisphere and in 15th-30th latitudes of Southern hemisphere. Minimum concentrations were observed in equatorial zone and in 50th latitudes of both hemispheres.

The data obtained show that absolute values of concentration of Beryllium-7 and fission fragment products change considerably in dependence of geographic coordinates. Beryllium-7 and fission fragment products concentrations ratio was found approximately equal for any geographical area (at the given time). Equatorial zone, where Beryllium-7 concentration is relatively higher, may be considered as an exception.

The high relative concentration of Beryllium-7 near the equator may be explained by the fact, that unlike other nuclear explosions products coming from the stratosphere, Beryllium-7 is mainly formad in the troposphere.

Handling of results of measurements has shown the following:

not later than in 2-3 months after the end of nuclear test series there established in both hemispheres rather .

stable meridional distribution of man-made activity in the near-ground air.

This distribution agrees in principle with meridional distribution of Beryllium-7. Distribution of man-made activity in the near-ground air is characterized by maximum concentrations in 20th-30th latitudes of both hemispheres and in polar areas and by minimums in equatorial zone and in 50-60th latitudes of both hemispheres.

3. Air Masses Exchange Between Hemispheres

Study of time distribution of nuclear explosions products along meridian allows to find out directly the nature of air mass exchange between the hemispheres. Comparison of measurement results of Cerium-144 concentration obtained from the data of expeditions on the ships "Ob"(December 1958 - April 1959) (8) and "M. Lomonosov" (9) (March 1961--June 1961) has shown, that between 50º N, and 30º S the ratio of Cerium-144 mean concentration in the Northern hemisphere to that in the Southern one does not change within ± 20% and is equal to 4 : 1 during 2.5 years. Comparison of measurement results, obtained on the ship "Estonija" during January-February 1963 and during January-February 1964 shows, that the ratio of hemisphere mean values of cerium-144 concentrations in the zone between 50º00' N and 66º00'S practically does not change during one year. Small number of measurements and short time period after the last nuclear test do not permit to perform quantitative calculations, which could characterize air masses exchange between hemispheres.

Above results, however, show that stratospheric activity reservoir is practically individual for each hemisphere. Estimations show that only some per cents of the whole stratospheric air take part in annual air exchange.

4. Influence of Meteorological Conditions on Radiactivity Level of the Near-Ground Air

In 1959 for tropical and subtropical zones of both hemispheres it was found, that the change of concentration of nuclear explosions products and Beryllium-7 was accompanied by simultaneous variation of the near-ground atmospheric pressure. The following investigations in large-scale of latitudes from 72º N up to 70º S verify the discovered regularity. At the same time it was ascertained that the rise of air activity was accompanied by the lowering of relative air humidity.

In this connection it was supposed that observed meridional distribution of activity was connected with magnitude and sign of air flow velocity (in vertical direction) typical for certain geographical areas.

It is known that the areas of high atmospheric pressure, as a rule, are characterized by descending flows of dry air masses, though sometimes the absolute value of atmospheric pressure in anticyclone during its break-up does not indicate magnitude and sign of vertical component of wind velocity.

The areas of low pressure are characterized by the ascending of hunid air masses. Vertical air motion influence was also retraced on synoprical maps: minimum concentration levels of radioactive products were observed at passing of cyclones and in central areas of equatorial depressions, maximum - in anticyclones and in the rears of cyclones.

Analysis of vertical aerological cuts of the atmosphere up to 30 km has shown that two types of perturbations are superposed to monotoneous distribution of radioactivity concentration along meridian in subtropical zone, caused by quasi-stationary anticyclones. The first perturbations are accompanied by formation of high-altitude frontal zone and

by jet streams, which lead to the tropopause break and to rising of radioactivity level up to nearly two times owing to exchange of stratospheric and tropospheric air masses. Other perturbations, which do not cause troposphere break (e.g. development of vortical movements on the equatorial side of anticyclones and in the zone of equatorial hollow) increase the near-ground air activity as more as 50 per cent. Boundaries of equatorial concentration minimum coincide with convergence zones, between which locate separate air masses formed on meridional sections of equivalentpotential or pseudopotential temperature.

The above-mentioned stable distribution of air radioactivity, near-ground atmospheric pressure and air humidity along meridian allow to suggest a hypothesis, that meridional circulation plays the main role in the process of activity descending from the upper atmosphere to the surface one. In accordance with the hypothesis major activity descending from upper atmosphere takes place in those earth zones where air masses sink i.e. in polar areas and in zones of subtropical quasi-stationary anticyclones.

In zones, where air masses ascend and prevent activity from descending, i.e. in equatorial zone and in 50th-60th latitudes of both hemispheres, there minimum activity levels of near-ground air are observed.

Fig.3 illustrates meridional distribution of Beryllium-7 and the near-ground atmospheric pressure along a meridian as well as a supposed meridional circulation, which explains activity distribution observed in the near-ground air.

Recently have been appeared meteorological whorks by Tucker (10), by Palmen and Vuorela (11); on basis of analysis of mean wind velocity at various altitudes in different geographical areas of Northern hemisphere they have

proved existence of direct tropical and inverse meanlatitudinal cells of meridional circulation.

There is not yet immediate meteorological evidence of existence of direct meridional circulation cell in polar regions (due to the lack of experimental data).

Suggested scheme of meridional circulation based on analysis of the near-ground activity distribution does not solve the problem of air masses exchange between the troposphere and stratosphere.

Comparatively stable configuration of the stratospheric reservoir observed over a long period of time permits to suppose that if circulation cells envelop some part of stratosphere then this envelopment affects the lowest stratosphere alone, adjastent to tropopause.

5. Distribution of Radioactive Products Concentration in the Upper Atmosphere

Systematical measurements of concentrations of radioactive products in upper atmosphere (up to 30 km) were mainly conducted above the Pacific Ocean. In summer 1962 one could observe in the stratosphere above Pacific a passage of radioactive clouds, caused then by nuclear explosions in equatorial area. The movement of clouds during some first days after the explosion was explained satisfactory by wind distribution. The most active parts (kernels) of radioactive clouds passed at altitudes of 20-24 km, near turn boundary of wind velocity zonal component. In 2-3 days after explosion their dimensions were of some thousands kilometers and corresponded to minimum values of vortical diffusion factor $K_z \approx 10^{10} cm^2/sec$.

Penetration of noticeable amounts of radioactive products from the stratosphere into the troposphere was not observed. Slight increase of concentration of fresh radio-

active products observed at passing of radioactive clouds into the stratosphere was explained by gravitational precipitation of the largest aerosol particles.

Radioactive products propagation in meridional direction was comparatively slow. Thus in the middle of August 1962 the zone of maximum concentration ($\geq 2 \cdot 10^{-8}$ c/st.m^3) of radioactive products was at altitudes of 22-25 km between 3ºN and 4ºS. From half-width of augmented concentrations region (2000 km) it was possible to evaluate vortical diffusion factor K_y. It was (3-4).10^9 cm^2/sec.

At the same time considerable deviations of radioactive clouds motion trajectories in the stratosphere from corresponding latitudes were observed in the mean latitudes.

Radioactive products transference by osten winds from polar and mean latitudes of Northern hemisphere to tropical zone boundaties during one-two weeks was noted in the beginning of September 1962 in the stratosphere above the Pacific. Appearance of radioactive products in the stratosphere was accompanied there by significant increase of their content in the troposphere and in the near-ground air layer.

Using meridional cross-section of the mentioned cloud the evaluation of the factor of cortical diffusion in meridional direction for the stratosphere of mean latitudes was made. It equals (/1-2/ $\cdot 10^9$ cm^2/sec), i.e. it was near to corresponding value for tropical zone stratosphere.

In spring 1963 Zinconium-95 and Niobium-95 concentration distribution was measured by means of spectrometric radiosondes along 180th longitude from 48ºN up to 40ºS.

The highest concentration of the mentioned nuclides was found in the stratosphere of the Northern hemisphere at altitudes of 18-20 km. From 20ºS to the South Zinconium-95 and Niobium-95 concentration in the stratosphere did not exceed instrument sensitivity threshold ($\sim 3 \cdot 10^{-10}$ c/st.m^3),

that indicated weak stratospheric exchange between hemispheres.

Intensive meridional motion of air masses was typical feature of meteorological situation over period of time considered.

Correlation between sign of meridional wind component and typical features of distribution of radioactive products was found. In particular, wind distribution explained qualitatively absence of noticeable quantities of radioactive products in the low stratosphere of tropical zone between equator and 25ºN up to altitude of 18 km.

The highest concentrations of radioactive products in the upper troposphere were observed between 35ºN and 25ºN, in the region of jet stream and tropopause break. Concentration rise in troposphere was accompanied there by noticeable decrease of Zirconium-95 and Niobium-95 concentration in the low stratosphere between 35ºN and 45ºN up to altitudes 15-16 km. Meteorological situation analysis (wind distribution and isentropic surfaces location) showed, that considerable adiabatic descending motions and intensive turbulent air exchange could take place in this district. According to the meteorological data, these motions related to the low stratosphere and troposphere (from 4 up to 14 km) and caused probably significant rise of Niobium-95 and Zirconium-95 concentration (till $3 \cdot 10^{-10}$ c/st.m^3) between 40ºN and 45ºN at altitudes 1-5 km. The pointed out zone of hightened concentrations was above highly developed inversion and isothermie layers, which, as known, made vertical air exchange essentially difficult.

The experimental data obtained allow to make the following conclusions about the law of movement of radioactive products in the stratosphere and about air exchange between the stratosphere and troposphere. In mean lati-

tudes because of significant trajectory deviations air masses motion from corresponding latitudes take place comparatively rapid spreading of radioactive products in meridional direction.

In some months radioactive products mix uniformly in low stratosphere. Meridional trajectory deviations in equatorial zone are considerably less and meridional transference is caused probably by weak vortical diffusion only. This apperently also explains observed little stratospheric exchange between hemispheres.

Radioactive products penetration from stratosphere into troposphere was insignificant in equatorial zone. The most quantities of radioactive products penetration from the stratosphere to the troposphere has been observed in zone of subtropical jet stream and tropopause break. Quasistationary adiabatic processes apparently play an important role in air exchange between the stratosphere and the troposphere in pointed region.

Conclusions

Experimental data obtained in the work on global distribution of radioactive products along with the results of other analogous investigations allow to make some conclusions in relation to features of air masses movement in the low stratosphere and troposphere.

1. Analysis of experimental data on distribution of nuclear explosion products in the stratosphere and distribution of radioactive products concentrations in the near-ground air layer show that comparatively quick (2-3 months) air mixing takes place in the stratosphere of middle latitudes because of considerable meridional transfer of air masses and because of vortical diffusion. Meridional components of winds in the tropical zone are insignificent. Therefore meridional transfer of air is caused only by

relatively weak vortical diffusion. These features of the stratosphere in tropical zone explain a small stratospheric exchange between the hemispheres. An evaluated annual stratospheric exchange does not exceed several per cents of total air in the stratosphere.

2. Air descent from stratosphere to the troposphere in tropical zone is insignificant. The most intensive exchange between stratosphere and troposphere in the middle latitudes takes place in the region of subtropical flow current and tropopause break. Considerable air descent from stratosphere takes place along isentropical surfaces.

3. The comparison of observed meridional distribution of radioactive products in the near-ground air with basic meteorological data has allowed to suppose an existence of three meridional circulation cells in the each hemisphere.

In accordance with this scheme ascent of air masses takes place in equatorial zone and in 50th-60th latitudes, and descent in 30th latitudes and in polar region.

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Explanations to Figures

Fig.1.

Gamma spectrum in energie region o.15-1.5 Mev measured by gamma spectrometric radiosonde on April 8, 1963 in the point of 16ºN, 180º. On the x-axis are there kicksorter channels, on the y-axis - number of counted pulses. Altitude intervals and measurement time are also indicated. Three maximum lines appear in the spectra (0.33; 0.5; 0.75 Mev). The first of them is of radioactive standard (Chromium-51) used for instruments check.

Fig.2.

Meridional distributions of beryllium-7(a), Tungsten-181 (b), Cerium-144 and total beta activity of fission products(c) in the near-ground air according to the data of sea expeditions.

Fig.3.

Mean meridional distribution of beryllium-7 concentration, near-ground atmospheric pressure and suggested scheme of meridional circulation.

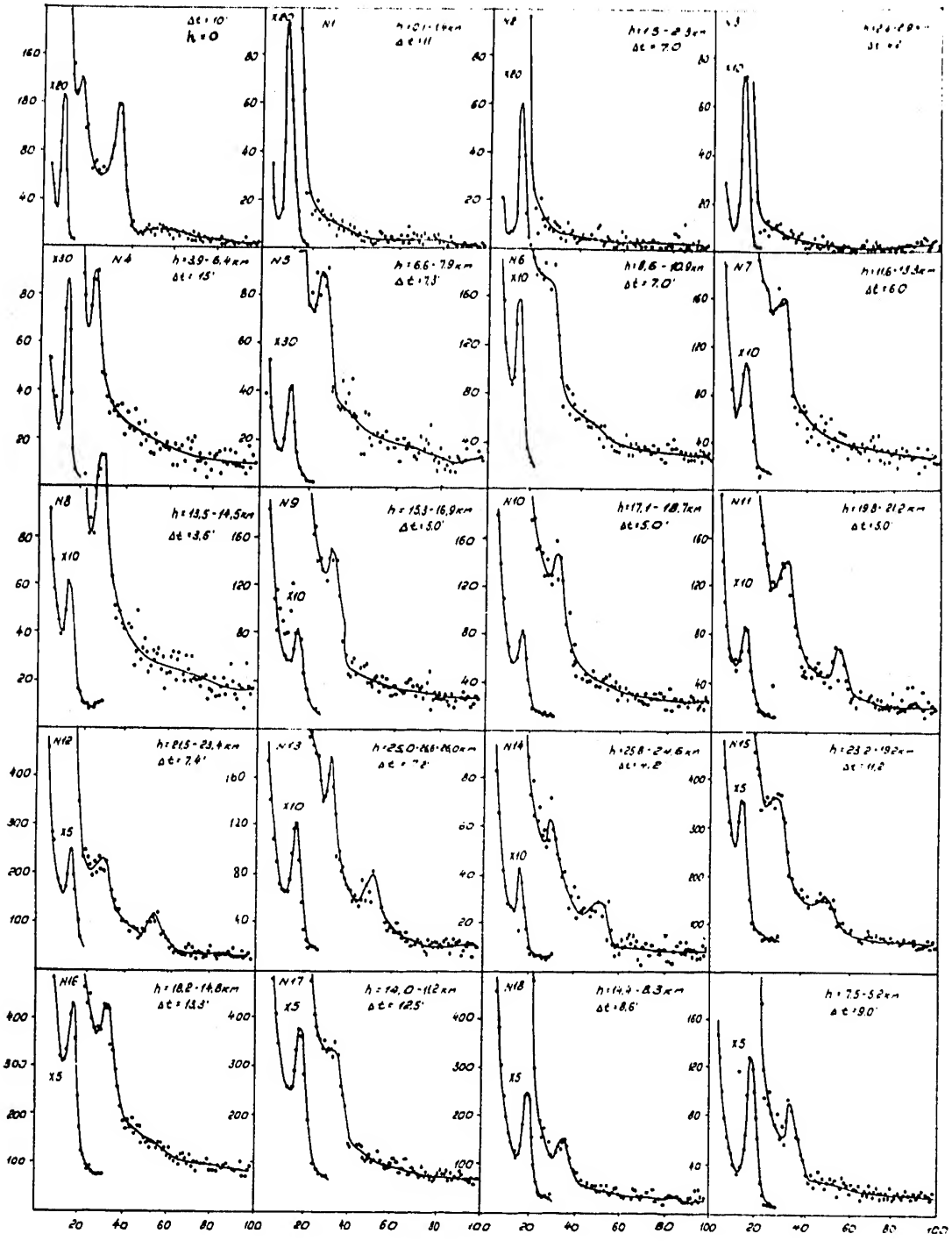

Fig. 1

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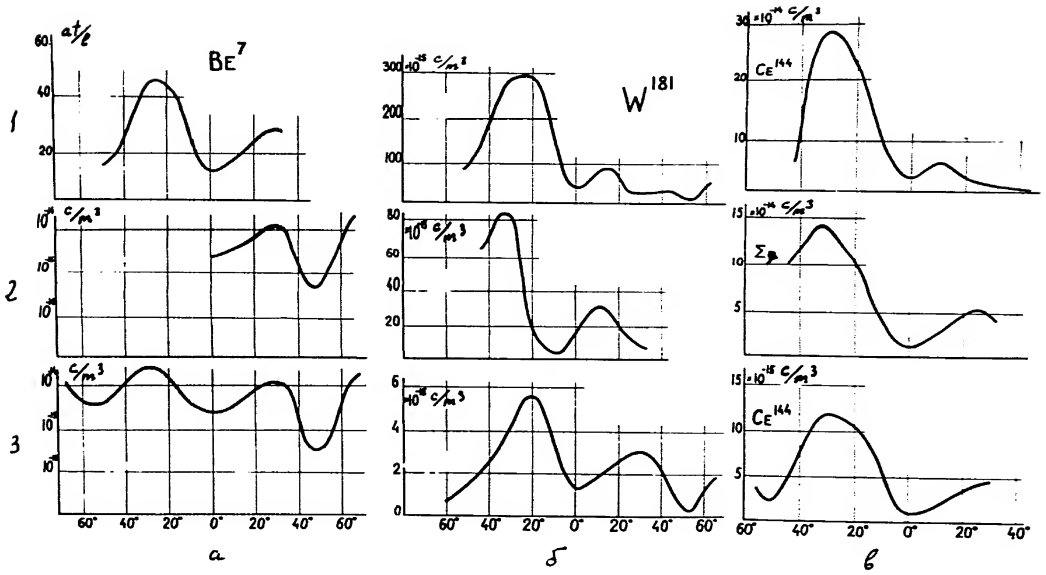

Fig. 2

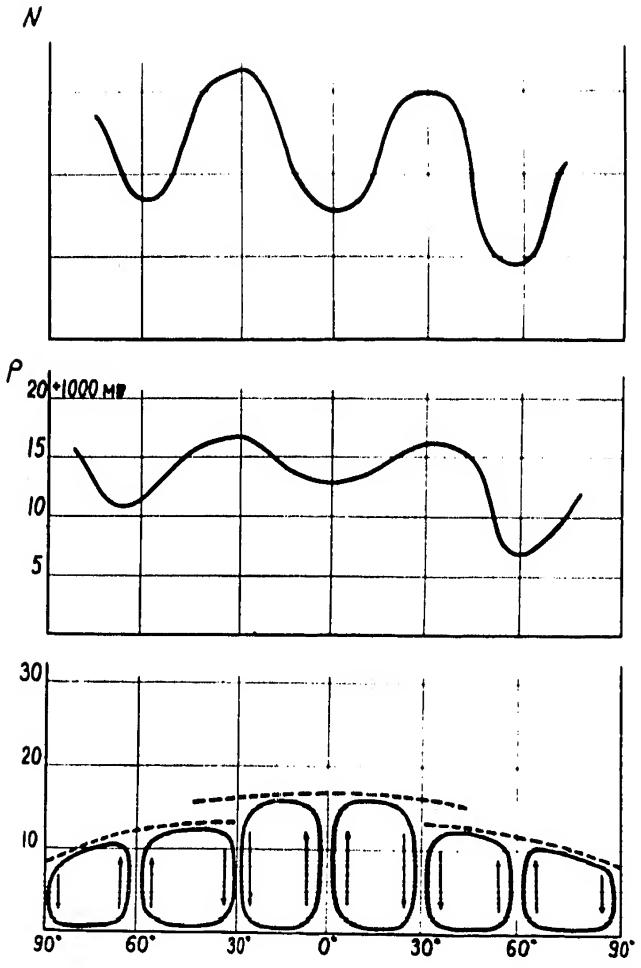

Fig. 3